SMOOTHING FACETS ON AN OPTICAL COMPONENT

1. Field of the Invention

[0001] The invention relates to optical components. In particular, the invention relates to smoothing facets positioned on the waveguides of optical components.

2. Background of the Invention

[0002] Optical networks employ a variety of optical components such as switches, demultiplexers, isolators, modulators and attenuators. Each optical component typically includes one or more waveguides for carrying the light signals to be processed by the optical component. These waveguides often end at a facet positioned at an edge of the optical component. Facets are often coupled with optical fibers that carry light signals to and/or from the optical component. Accordingly, light signals are often transmitted through a facet.

[0003] A light signal transmitted through a facet can be reflected by the facet. Reflected light signals are a source of optical loss and noise. The amount of reflection that occurs at the facet increases as the roughness of the facet increases. Lapping or polishing techniques can be employed to smooth a facet positioned at an edge of an optical component in order to improve the optical performance of the facet. The currently available polishing and techniques are inefficient and not suitable for large scale production of optical components. As a result, there is a need for improved facet smoothing techniques.

SUMMARY OF THE INVENTION

[0004] The invention relates to a method of smoothing facets on optical components. The method includes forming a plurality of optical components into a block of optical components. The method also includes smoothing one or more sides of the block of optical components. The one or more smoothed sides are at least partially defined by edges of the optical components. In some instances, the edges of the optical

components that define the one or more smoothed sides of the block include one or more waveguide facets.

[0005] The invention also relates to a system for holding a block of optical components to be smoothed. The system includes a base having a recess configured to receive the block of optical components. A bottom of the recess extends to an external side of the base such that a block of optical components positioned on the bottom of the recess can extend from within the recess past the external side of the recess. The system also includes a cover configured to be positioned over the recess so as to clamp the block of optical components between the cover and the base.

[0006] The invention also relates to a method of forming a block of optical components. The method includes positioning a plurality of optical components adjacent to one another with a bonding medium positioned between adjacent optical components. The method also includes aligning at least one edge of the optical components.

[0007] The invention also relates to a jig for aligning an edge of optical components. The jig includes a base having an optical component positioning region for positioning a block of optical components. The jig also includes two or more alignment members adjacent to the optical component positioning region. At least one of the alignment members is movable relative to one or more alignment members positioned on an opposing side of the optical component positioning region.

BRIEF DESCRIPTION OF THE FIGURES

[0008] Figure 1A is a top view of an optical component having a facet that can be smoothed according to the present invention.

[0009] Figure 1B is a top view of a portion of the optical component shown in Figure 1A.

[0010] Figure 1C is a side view of the optical component shown in Figure 1B taken in the direction of the arrow labeled A.

[0011] Figure 1D is a cross section of an optical component taken along a longitudinal axis of a waveguide.

[0012] Figure 2A is a perspective view of a jig for aligning a plurality of optical components.

[0013] Figure 2B is a top view of the alignment jig shown in Figure 2A.

[0014] Figure 2C is a side view of the alignment jig shown in Figure 2B taken in the direction of the arrow labeled A in Figure 2B.

[0015] Figure 3A through Figure 3F illustrate a method of operating an alignment jig so as to form a block of optical components having one or more aligned edges.

[0016] Figure 4A is a top view of the base of a holder that is suitable for holding a block of optical components while smoothing a side of the block.

[0017] Figure 4B is a side view of the base shown in Figure 4A taken in the direction of the arrow labeled A.

[0018] Figure 4C is a cross section of the base shown in Figure 4A taken along the line labeled B.

[0019] Figure 4D is a side view of the base shown in Figure 4B taken in the direction of the line labeled C.

[0020] Figure 4E is a side view of the base shown in Figure 4B taken in the direction of the line labeled D.

[0021] Figure 4F is a top view of a cover that is suitable for use with the base illustrated in Figure 4A through Figure 4E.

[0022] Figure 4G is a side view of the cover shown in Figure 4F taken in the direction of the arrow labeled A.

[0023] Figure 4H is a side view of the cover shown in Figure 4F taken in the direction of the arrow labeled B.

[0024] Figure 4I is bottom view of the cover illustrated in Figure 4F.

[0025] Figure 5A through Figure 5D illustrate a method of operating a holder so as to hold a block of optical components.

[0026] Figure 6A is a side view of a polishing jig that is suitable for holding the holder during smoothing of the block of optical components.

[0027] Figure 6B is a cross section of the polishing jig shown in Figure 6A taken along the line labeled A.

[0028] Figure 7A through Figure 7C illustrate a method of operation of a polishing jig so as to polish one or more sides of the block of optical components.

[0029] Figure 8A is a top view of a holder that is suitable for forming a facet angled at less than ninety degrees relative to the direction of propagation of light signals along a waveguide.

[0030] Figure 8B is a cross section of the base shown in Figure 8A along the line labeled A with a cover positioned over the base.

[0031] Figure 9A through Figure 9C illustrate a method of operating the holder illustrated in Figure 8A and Figure 8B so as to form a facet angled at less than ninety degrees relative to the direction of propagation of light signals along a waveguide.

[0032] Figure 10A through Figure 10B illustrate a method of operating another embodiment of a holder so as to form a facet angled at less than ninety degrees relative to the direction of propagation of light signals along a waveguide.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0033] The invention relates to smoothing facets on optical component. A plurality of optical components is formed into a block. The block is formed such that the edges of the optical components define one or more sides of the block. One or more sides of the block defined by edges of the optical components are smoothed. The edges of the optical components that define the one or more smoothed side can include waveguide facets. As a result, smoothing the side of the block also serves to smooth the facets of the optical components. Hence, the facets on a plurality of optical components can be concurrently smoothed. The ability to concurrently smooth the facets on a plurality of optical components makes smoothing of the facets of optical components a viable step in large scale fabrication of optical components.

[0034] Figure 1A through Figure 1D illustrate an example of an optical component 10. A facet 12 is positioned at an edge 14 of the optical component 10. Figure 1A is a top view of the optical component 10. Figure 1B is a top view of a portion of the optical component 10 shown in Figure 1A. Figure 1C is a side view of the optical component 10 shown in Figure 1B taken in the direction of the arrow labeled A. Although the edges 14 of the optical component 10 is illustrated as defining a rectangular shape, the optical component 10 can have edges 14 that define a variety of different geometries and can include one or more curved edges 14.

[0035] The component 10 includes a light transmitting medium 18 formed over a base 20. The light transmitting medium 18 includes a ridge 22 that defines a portion of the light signal carrying region 24 of a waveguide 26. Suitable light transmitting media include, but are not limited to, silicon, polymers, silica, SiN_x, $LiNbO_3$, GaAs and InP. The base 20 is configured to reflect light signals from the light signal carrying region 24 back into the light signal carrying region 24. As a result, the base 20 also defines a portion of the light signal carrying region 24. The line labeled E illustrates the profile of a light signal carried in the light signal carrying region 24.

[0036] The waveguide 26 ends at a facet 12 positioned at an edge 14 of the optical component 10. Light signals can enter and/or exit the waveguide 26 through the facet 12. Reflection of a light signal at the facet 12 is a source of optical loss and noise associated with the optical component 10. A smoother facet 12 produces less reflection than a rough facet 12. As a result, a smooth facet 12 can reduce the amount of optical loss and noise associated with an optical component 10.

[0037] The facet 12 can be angled at less than ninety degree relative to the direction of propagation of light signals traveling along the waveguide 26. For instance, Figure 1D is a cross section of the optical component 10 taken along the longitudinal axis of a waveguide 26. Figure 1D could be a cross section of the optical component 10 shown in Figure 1B taken at the line labeled B. The facet 12 illustrated in Figure 1D is positioned at an angle ϕ relative to the direction of propagation of light signals along the waveguide 26. As illustrated by the arrow labeled A, a light signal reflected at the facet 12 can be reflected out of the waveguide 26. As a result, the reflected light signal is not a source of resonance in the waveguide 26. Suitable angles, ϕ, include, but are not limited to, angles in a range from 45° - 89°, 70° - 88°, 80° – 85° or 82° – 84°.

[0038] An example of a method for smoothing the facets 12 of an optical component 10 includes forming a plurality of optical components 10 into a block 60. One or more sides of the block 60 are smoothed such that facets 12 positioned at the smoothed side of the block 60 are also smoothed.

[0039] Figure 2A through Figure 2C illustrate an alignment jig 30 that is suitable for forming a block of optical components 10 having one or more aligned edges 14. Figure 2A is a perspective view of the alignment jig 30 and Figure 2B is a top view of the alignment jig 30. Figure 2C is a side view of the alignment jig 30 taken in the direction of the arrow labeled A in Figure 2B.

[0040] The alignment jig 30 includes a base 32 having a platform 34. A plurality of alignment members 36 are positioned adjacent to a component positioning region 42.

For instance, the base 32 includes a fixed alignment member 38 and a plurality of mobile alignment members 40. The fixed alignment member 38 and mobile alignment members 40 are positioned on opposing sides of an optical component positioning region 42. As will become evident below, optical components 10 are positioned in the optical component positioning region 42 during operation of the alignment jig so as to align one or more edges of the optical components.

[0041] The fixed alignment member 38 is immobilized relative to the base 32. The fixed alignment member 38 can be integral with the base 32 or can be attached to the base 32. As will become evident below, a portion of the fixed alignment member 38 has a contour that is complementary to one or more sides of the optical components 10 so optical components 10 can be positioned against the fixed alignment member 38.

[0042] The mobile alignment members 40 can be move relative to an alignment member positioned on an opposing side of the component positioning region. Each mobile alignment member 40 includes an immobilizing device 44 for immobilizing the mobile alignment member 40 relative to the base 32. A suitable immobilizing device 44 is a screw that screws into the base 32. The screw can pass through an opening 46 in the mobile alignment members 40. When the screw is tightened against the mobile alignment members 40, the mobile alignment member 40 is immobilized relative to the platform 34. When the screw is loosened, the mobile alignment member 40 is mobile relative to the platform 34 as shown by the arrows labeled B. Accordingly, the mobile alignment member 40 can be moved to a particular location on the platform 34 and locked into position on the platform 34.

[0043] The alignment members 36 each include a component contact region 48. As will be shown in more detail below, the component contact region 48 of an alignment member 36 is the region of the alignment member 36 that contacts the optical components 10 being aligned by the alignment jig 30. The component contact region 48 of alignment members 36 positioned on opposing sides of the components positioning region 42 are parallel to one another.

[0044] An arm 50 and an arm support 52 are positioned over the platform 34. The arm 50 can be rotated about an axis as illustrated by the arrow labeled C. The arm 50 can be moved into contact with the arm support 52. The arm support 52 includes an immobilizing device 44 that can be employed to immobilize the arm 50 relative to the arm support 52. An example of an immobilizing device 44 is a screw that screws into the arm support 52. The arm 50 can include a recess 54. When the arm 50 is in contact with the arm support 52, the screw can be received in the recess 54. The screw can be tightened against the arm 50 to immobilize the arm 50 relative to the platform 34.

[0045] The arm 50 includes one or more alignment devices 56. The one or more alignment devices 56 can be moved relative to the platform 34 as indicated by the arrows labeled D in Figure 1C. The one or more alignment devices 56 are positioned on the arm 50 so as to be positioned over the optical component positioning region 42 when the arm 50 is positioned in contact with the arm support 52. Accordingly, the one or more alignment devices 56 can apply a downward pressure to optical components 10 positioned in the optical component positioning region 42. A example of a suitable alignment devices 56 is a screw that passes through the arm 50 and that can be threaded into the arm 50. Accordingly, loosening the screw moves the end of the screw away from the optical component positioning region 42 and tightening the screw moves the end of the screw toward the optical component positioning region 42. The screw can be tightened enough to apply pressure to optical components 10 positioned in the optical component positioning region 42.

[0046] Although the component contact regions 48 illustrated above are shown as being substantially perpendicular to the base 32, the component contact regions 48 can be non-perpendicular while component contact regions 48 on opposing sides of the component positioning region 42 are parallel. This arrangement causes the edges 14 of the optical components 10 to be aligned at an angle.

[0047] Although the alignment jig 30 shows one mobile alignment member 40 positioned adjacent to a side of the component positioning region 42, more than one

mobile alignment member 40 can be positioned adjacent to a side of component positioning region 42.

[0048] Figure 3A through Figure 3F illustrate a method of operating the alignment jig 30 so as to form a block 60 of optical components 10 having one or more aligned edges. The alignment jig 30 is heated to a temperature sufficient for melting a bonding medium for bonding the optical components 10 together. A suitable bonding medium includes, but is not limited to, wax such as quartz wax or white wax. When the bonding medium is quartz wax, a suitable temperature for the alignment jig 30 is about 100 °C and when the bonding medium is white wax, a suitable temperature for the alignment jig 30 is about 55-59 °C. A suitable material for the alignment jig 30 includes, but is not limited to, aluminum. An alignment jig 30 constructed from a material such as aluminum can be heated to the desired temperature by placing the alignment jig 30 on a heating plate.

[0049] A plurality of optical components 10 are positioned in the optical component positioning region 42 as illustrated in Figure 3A and Figure 3B. Figure 3A is a top view of the alignment jig 30 and Figure 3B is a cross section of the alignment jig 30 shown in Figure 3A taken at the line labeled A. As shown in Figure 3A and Figure 3B, the optical components 10 each have about the same geometry and can be positioned in the optical component positioning region 42 without the edges 14 of the optical components 10 being aligned. The optical components 10 can be positioned on the platform 34 sequentially. A layer of bonding medium can be positioned on each optical component 10 before another optical component 10 is positioned on the platform 34. Accordingly, the bonding medium is positioned between the optical components 10. The bonding medium can be positioned on the optical components 10 in a fluid state or in a solid state.

[0050] One or more of the optical components 10 can be a dummy optical component. For instance, the top optical component 10 and/or the bottom optical component 10 can be a dummy optical component. A suitable dummy optical

component includes a silicon substrate having a geometry that matches the geometry of the optical components 10.

[0051] Although Figure 3A through Figure 3F illustrate the block 60 including six optical components 10, the block 60 can include two or more optical components 10. A suitable number of optical components for the block include, but are not limited to, four or more optical components, seven or more optical components, 10 or more optical components, and 14 or more optical components.

[0052] The mobile alignment members 40 are moved into contact with the optical components 10 as shown in Figure 3C and Figure 3D. Figure 3C is a top view of the alignment jig 30 and Figure 3D is a cross section of the alignment jig 30 shown in Figure 3C taken at the line labeled A. One of the mobile alignment members 40 is moved in the direction of the arrow labeled B and the other mobile alignment members 40 is moved in the direction of the arrow labeled C. The movement of the mobile alignment members 40 drives the optical components 10 against the fixed alignment member 38. Because the optical components 10 are about the same size and because the component contact regions 48 are parallel, the movement of the mobile alignment member 40 causes the edges 14 of the optical components 10 to line up along the contact regions 48 of the fixed alignment member 38 and the mobile alignment members 40. As a result, the movement of the mobile alignment member 40 causes the edges 14 of the optical components 10 to be aligned with one another.

[0053] The shape and positioning of the fixed alignment member prevents the block of optical components from twisting or rotating in response to the forces created by movement of the mobile alignment member. Although a one piece fixed alignment member is shown, the function of the fixed alignment member 38 can be achieved with a plurality of alignment members 36 positioned adjacent to the component positioning region so as to provide the functions of the single fixed alignment member.

[0054] The arm 50 is positioned in contact with the arm support 52 as shown in Figure 3E and Figure 3F. Figure 3E is a top view of the alignment jig 30 and Figure 3F is a cross section of the alignment jig 30 shown in Figure 3E taken at the line labeled A. The immobilizing device 44 on the arm support 52 is engaged so as to immobilize the arm 50 relative to the platform 34. The alignment devices 56 are engaged so as to apply a downward pressure on the optical components 10. Further, the alignment devices 56 are engaged so the distance between the end of each alignment device 56 and the platform 34 is the same. For instance, when the alignment device 56 is a screw that is threaded into the arm 50, each alignment device 56 can be threaded the same distance into the arm 50. Because the distance between the end of each alignment device 56 and the platform 34 is the same, the thickness of the block 60 under one of the alignment devices 56 is the same as the thickness of the block 60 under the other alignment device 56. As a result, the optical components 10 are substantially parallel to each other.

[0055] The alignment jig 30 can be allowed to cool and the block 60 can be removed from the alignment jig 30. Alternatively, the block 60 can be removed before the alignment jig 30 is cooled. Cooling of the block 60 allows the bonding medium to bond the optical components 10 together. As a result, the optical components 10 can be handled as a block 60 after cooling of the optical components 10.

[0056] Before the alignment jig 30 is cooled, the immobilizing devices 44 can be engaged so as to immobilize the mobile alignment members 40 relative to the base 32. Engaging the immobilizing devices 44 allows the block 60 of optical components 10 to retain the desired shape during the cooling process. The immobilizing devices 44 can be engaged at other times during formation of the block 60. For instance, the immobilizing devices 44 can be engaged before the arm 50 is positioned over the component positioning region 42. Further, the immobilizing devices 44 associated with each mobile alignment member can be engaged after moving the mobile alignment member into contact with the optical components.

[0057] Although the alignment jig 30 of Figure 3A through Figure 3F shows a fixed alignment member 38, the alignment of the optical component edges 14 can be achieved with mobile alignment members 40 positioned on opposing sides of the component positioning region 42. For instance, one of the mobile alignment members 40 can be immobilized using an immobilizing device 44 and another mobile alignment member 40 employed to drive the optical components 10 against the immobilized mobile alignment member 40. Alternatively, mobile alignment members 40 on opposing sides of the optical components 10 can be moved toward one another.

[0058] Although Figure 2A through Figure 3F illustrate the alignment jig 30 employed to align the edges 14 on each side of the optical components 10, there may be circumstances where it is desired to align the edges 14 on only one side of the optical components 10. As a result, alignment members 36 need not be positioned adjacent to each side of the component positioning region 42. For instance, the alignment jig 30 illustrated in Figure 2A can include a single mobile alignment member 40. Operating an alignment jig 30 having a single mobile alignment member 40 results in alignment of the optical component edges 14 on at least one side of the block 60.

[0059] Figure 4A through Figure 4I illustrate an example of a holder 64 for holding a block 60 of optical components 10 while smoothing a portion of the block 60. The holder 64 includes a cover configured to be moved relative to a base 68. Figure 4A through Figure 4E illustrate different views of a suitable base 68. Figure 4A is a top view of the base 68. Figure 4B is a side view of the base 68 shown in Figure 4A taken in the direction of the arrow labeled A. Figure 4C is a cross section of the base 68 shown in Figure 4A taken along the line labeled B. Figure 4D is a side view of the base 68 shown in Figure 4B taken in the direction of the line labeled C. Figure 4E is a side view of the base 68 shown in Figure 4B taken in the direction of the line labeled D.

[0060] The base 68 includes a top side 70, a bottom side 72, a front side 74 and a back side 76. The top side 70 includes a plurality of threaded openings 78 and the back side 76 includes one or more threaded openings 78. The bottom side 72 of the base 68 includes a first recess 80. The first recess 80 reduces the weight of the holder 64.

[0061] The top side 70 of the base 68 includes a second recess 82. The bottom of the second recess 82 extends to the front side 74 of the holder 64. The second recess 82 has a shape that is complementary to the shape of a portion of the block 60 so the block 60 can be positioned in the second recess 82 without substantial movement of the block 60 relative to the second recess 82.

[0062] Figure 4F through Figure 4I illustrate different views of a cover 84 that is suitable for use with a base 68 constructed according to Figure 4A through Figure 4E. Figure 4F is a top view of the cover 84. Figure 4G is a side view of the cover 84 shown in Figure 4F taken in the direction of the arrow labeled A. Figure 4H is a side view of the cover 84 shown in Figure 4F taken in the direction of the arrow labeled B. Figure 4I is bottom view of the cover 84 illustrated in Figure 4F.

[0063] A bottom side 72 of the cover 84 includes a ridge 86. The ridge 86 is shaped such that the cover 84 can be positioned on the base 68 with the ridge 86 positioned in the second recess 82. Additionally, the ridge 86 can have a shape that is complementary to the shape of the second recess 82. The complementary shape of the ridge 86 reduces movement of the ridge 86 relative to the second recess 82 when the cover 84 is positioned on the base 68.

[0064] The cover 84 also includes a plurality of couplers 88 for coupling the cover 84 with the base 68. Suitable couplers 88 include, but are not limited to, screws configured to be screwed into the threaded openings 78 in the top side 70 of the holder 64. The screws extend through the cover 84 such that an end of the screw is positioned adjacent to the ridge 86.

[0065] Although the cover 84 is shown as being detached from the base 68, the cover 84 can be coupled with the base 68. For instance, the cover 84 can be hinged to the base 68.

[0066] Figure 5A through Figure 5D illustrate operation of the holder 64 to hold a block 60 of optical components 10. Figure 5A is a top view of a holder 64 holding a block 60 of optical components 10. Figure 5B is a side view of the holder 64 shown in Figure 5A taken in the direction of the arrow labeled A. Figure 5C is a cross section of the holder 64 shown in Figure 5A taken along the line labeled B. Figure 5D is a side view of the holder 64 shown in Figure 5A taken in the direction of the arrow labeled C.

[0067] During operation of the holder 64, the block 60 of optical components 10 are positioned in the second recess 82 in the top of the base 68. The block 60 is positioned against a back side of the second recess 82. Because the second recess 82 has a shape that is complementary to the shape of the block 60, the block 60 fits in the second recess 82 with little freedom to move relative to the second recess 82. The cover 84 is positioned on the base 68 with the ridge 86 positioned in the second recess 82. The couplers 88 are screwed into the threaded openings 78 on the top side 70 of the base 68 until the block 60 is clamped between the cover 84 and the bottom of the second recess 82. If the block 60 is too narrow to be clamped between the cover 84 and the bottom of the second recess 82, shims can be employed between the block 60 and cover 84 and/or between the block 60 and/or the bottom of the second recess 82.

[0068] At least a portion of a side of the block 60 extends from the front side 74 of the holder 64 as is evident in Figure 5A through Figure 5C. As will be shown in more detail below, the exposed side of the block 60 is the side of the block 60 to be smoothed. Accordingly, the block 60 is positioned in the holder 64 so the exposed portion of the block 60 includes facets 12 to be smoothed.

[0069] Figure 6A and Figure 6B illustrate a polishing jig 90 that is suitable for holding the holder 64 during smoothing of the block 60 of optical components 10.

Figure 6A is a side view of the polishing jig 90. Figure 6B is a cross section of the polishing jig 90 shown in Figure 6A taken along the line labeled A. The polishing jig 90 includes a frame 92 defining a chamber for holding the holder 64. The frame 92 includes an upper opening 94 and a lower opening 96. The frame 92 holds a carriage 98 that extends through the upper opening 94. The carriage 98 can be moved up and down within the frame 92.

[0070] A rod 100 extends through the carriage 98. The rod 100 includes an end with threads 102 and an end with a head 104. The threads 102 on the end of the rod 100 are complementary to the threads of the threaded opening 78 on the back side 76 of the holder 64. The head 104 can be turned to rotate the rod 100 in the carriage 98.

[0071] A micrometer 106 is positioned over the upper opening 94. Gravity holds the micrometer 106 against the frame 92. The micrometer 106 can be threaded onto the carriage 98. Rotating the micrometer 106 in a first direction around the carriage 98 moves the carriage 98 up relative to the frame 92 while rotating the micrometer 106 in a second direction around the carriage 98 moves the carriage 98 down relative to the frame 92.

[0072] Feet 108 are positioned at a bottom of the frame 92. During the smoothing process, the feet 108 are positioned on the smoothing mechanism. For instance, if the smoothing process is polishing, the feet 108 can be positioned on a polishing wheel during the smoothing process. The feet 108 are constructed from a material that resists breaking down in response to the smoothing process. For instance, if the smoothing process is polishing, the feet 108 can be constructed from diamond.

[0073] The frame 92 can optionally include one or more openings 110 through the side of the frame 92. The one or more openings 110 can be selected to reduce the weight of the polishing jig 90.

[0074] Figure 7A through Figure 7C illustrate operation of the polishing jig 90. Figure 7A is a side view of the polishing jig 90 holding the holder 64. Figure 7B is a cross section of the polishing jig 90 illustrated in Figure 7A.

[0075] During operation of the polishing jig 90, the holder 64 is positioned in the frame 92 such that the exposed portion of the block 60 extends through the lower opening 96. The threaded end of the rod 100 is threaded into the threaded opening 78 in the back side 76 of the holder 64. As a result, the holder 64 is immobilized relative to the carriage 98.

[0076] The micrometer 106 is adjusted so as to move the carriage 98 up or down in the frame 92. The micrometer 106 is adjusted so the exposed portion of the block 60 extends a desired distance past the feet 108. The distance of the exposed region past the feet 108 is the total amount of the block 60 can be removed from the block 60 during the smoothing process. For instance, when the block 60 extends 2 μm past the feet 108 at most 2 μm can be removed from the block 60 as a result of the smoothing process.

[0077] The exposed portion of the block 60 is smoothed. Suitable techniques for smoothing the block 60 include, but are not limited to, polishing, buffing and lapping. The polishing jig 90 is set on a smoothing device 112 as illustrated in Figure 7C. Suitable smoothing devices 112 include, but are not limited to, polishing wheels, buffing wheels and lapping wheels. A suitable polishing wheel includes, but is not limited to, the lapping and polishing equipment manufactured by South Bay Technology, Inc. located in San Clemente, CA.

[0078] In Figure 7C, the carriage 98 shifts upward in the frame 92 until the feet 108 and the exposed portion of the block 60 rest on the smoothing device 112. The weight of the carriage 98 on the block 60 pushes the block 60 onto the smoothing device 112. The smoothing device 112 moves under the block 60 and includes an abrasive material. The movement of the abrasive material relative to the exposed portion of the block 60 serves to smooth the exposed portion of the block 60.

Smoothing of the exposed portion of the block 60 smoothes the facets 12 positioned on the exposed portion of the block 60.

[0079] The amount of smoothing that occurs depends on the selection of the abrasive material. The highest degree of smoothness can be achieved by moving from a coarse abrasive material toward a fine abrasive material. An example of a suitable smoothing scheme includes using a 30 μm grid abrasive material, followed by a 9 μm grid abrasive material, followed by a 6 μm grid abrasive material, followed by a 3 μm grid abrasive material, followed by a 1 μm grid abrasive material, followed by a .02 μm grid abrasive material.

[0080] Suitable materials for the holder 64 and the polishing jig 90 are rigid enough to withstand the stresses of the smoothing process without substantially deforming. Suitable materials include, but are not limited to, stainless steel.

[0081] After a suitable level of smoothness is achieved, the holder 64 can be removed from the smoothing jig and the block 60 removed from the holder 64. The optical components 10 in the block 60 can be separated from one another. A suitable method for separating the optical components 10 from one another includes, but is not limited to, heating the block to a temperature that allows the optical components 10 to be physically separated. The separated optical components 10 can then be placed in a cleaning solvent. For example, when the bonding medium is a wax, a solvent such as OPTICLEAR employed to remove the wax.

[0082] When the optical components 10 in the block 64 have more than one edge with facets to be smoothed, the block 60 can be placed back in the holder 64 so a different side of the block is exposed before the optical components 10 are separated from one another. The newly exposed side can be smoothed as described above. As a result, the facets one more than one edge of the optical component can be smoothed. The block 60 can be removed from the holder 64, replaced in the holder 64 and smoothed until each sides where smoothing is desired is smoothed. Once the desired

sides are smoothed, the optical components 10 can be separated from one another as described above.

[0083] As noted above, the one or more facets 12 can be angled at less than ninety degrees relative to the direction of propagation of light signals along a waveguide. Figure 8A and Figure 8B illustrate a holder 64 that is suitable for forming a facet 12 angled at less than ninety degrees relative to the direction of propagation along a waveguide. Figure 8A is a top view of the base 68 of the holder 64. Figure 8B is a cross section of the base 68 shown in Figure 8A along the line labeled A with a cover 84 positioned over the base 68.

[0084] The bottom of the second recess 82 and the portion of the cover 84 are angled relative to the longitudinal axis of the holder 64 at an angle, θ. The longitudinal axis of the holder 64 is the axis of the holder 64 that is to be positioned perpendicular to the abrasive material of the smoothing device 112. For instance, Figure 7C illustrates the holder 64 positioned so the length of the holder 64 is vertical relative to the abrasive material of the smoothing device 112. The line labeled A in Figure 8A or Figure 8B is parallel to the length of the holder 64. Accordingly, the line labeled A in Figure 8A or Figure 8B denotes a longitudinal axis of the holder 64.

[0085] Figure 9A through Figure 9C illustrate operation of the holder 64 illustrated in Figure 8A and Figure 8B. The block 60 of optical components 10 are positioned in the second recess 82 as shown in Figure 9A. The block 60 is positioned so at least a portion of the block 60 is in contact with a back of the second recess 82. The cover 84 is positioned on the base 68 with the ridge 86 positioned in the second recess 82. The couplers 88 are screwed into the threaded openings 78 on the top side 70 of the base 68 until the block 60 is clamped between the cover 84 and the bottom of the second recess 82. Because the bottom of the second recess 82 is angled at $\theta°$ relative to the longitudinal axis of the holder 64 at an angle θ, the exposed side of the block 60 is angled at $\theta°$ relative to the front side 74 of the holder 64. The front side 74 of the holder 64 is the portion of the holder 64 that is to be positioned parallel to the

abrasive material of the smoothing device 112. Accordingly, the block 60 extends from the holder 64 such that a side of the block 60 is angled at 90°-θ relative to the longitudinal axis as shown in Figure 9A.

[0086] The holder 64 is positioned in the polishing jig 90 and the exposed portion of the block 60 is smoothed. The block 60 is smoothed parallel to the front side 74 of the holder 64 as illustrated in Figure 9B. Because the block 60 extends from the holder 64 at an angle at 90°-θ relative to the longitudinal axis, the exposed side of the block 60 is smoothed at 90°-θ. When the optical components 10 are separated, the edge 14 of the each optical component 10 also has an angle of 90°-θ as shown in Figure 9C. The facets 12 positioned at the edge 14 of the optical component 10 are also formed at an angle 90°-θ. The angle 90°-θ is labeled as ϕ in Figure 1D. As a result, the holder 64 is designed with an angle θ that provides optical components 10 with the desired ϕ.

[0087] Although Figure 9A illustrates the second recess 82 formed so a gap is formed between a portion of the block 60 and the back of the second recess 82, the second recess 82 can be formed so the back of the second recess 82 is flush with the block 60.

[0088] Figure 10A and Figure 10B illustrate another embodiment of a holder 64 configured to form facets 12 angled at less than ninety degrees relative to a direction of propagation of light signals along a waveguide. The sides of the second recess 82 are formed at an angle, θ, relative to the longitudinal axis of the holder 64. When the block 60 is positioned in the second recess 82 as shown in Figure 10B, the exposed portion of the block 60 extends from the holder 64 at an angle θ relative to the front side 74 of the holder 64. Because the smoothing process smoothes the block 60 parallel to the front side 74 of the holder 64, the exposed side of the block 60 is smoothed at an angle θ. When the optical components 10 are separated, the edge 14 of the each optical component 10 also has an angle of 90°-θ. The facets 12 positioned at the edge 14 of the optical component 10 are also formed at an angle 90°-θ. The

angle 90°-θ is turned 90° relative to the angle labeled ϕ in Figure 1D, however, the angle 90°-θ will provide the same function as the angle labeled ϕ. As a result, the holder 64 is designed with an angle θ that provides optical components 10 with the desired ϕ.

[0089] As noted above, suitable values for the angle labeled ϕ in Figure 1D include, but are not limited to, angles less than 89°, 45° - 89°, 70° - 88°, 80° – 85° or 82° – 84°. Accordingly, suitable values for the angle labeled θ in Figure 8A through Figure 10B include, but are not limited to angles greater than 1°, 45° - 1°, 2-20°, 5° – 10° or 6-8°.

[0090] When more than one side of the block 60 is to be smoothed, the block 60 can be placed in different holders 64 during the smoothing of different sides. For instance, the block 60 can be placed in a holder 64 is suitable for forming a facet at a first angle relative to the direction of propagation along a waveguide during smoothing of a first side of the block 60. The block 60 can then be placed in a holder 64 suitable for forming a facet at a second angle relative to the direction of propagation along a waveguide during smoothing of a second side of the block 60.

[0091] Although the invention is disclosed in the context of optical components 10 having edges 14 that define a rectangular perimeter, the invention can be employed in conjunction with optical components 10 having edges 14 that define other shapes.

[0092] Although the optical components 10 disclosed above have a ridge waveguide, the optical components 10 can have other waveguide types including, but not limited to, buried channel waveguides and strip waveguides.

[0093] Other embodiments, combinations and modifications of this invention will occur readily to those of ordinary skill in the art in view of these teachings. Therefore, this invention is to be limited only by the following claims, which include all such embodiments and modifications when viewed in conjunction with the above specification and accompanying drawings.